Developmental Fisheries Progress Report: Brine Shrimp

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TABLE OF CONTENTS

TABLE OF CONTENTS (con't)

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In 1996, ODFW received numerous inquiries about harvesting brine shrimp cysts from Lake Abert; much of the interest coming from the expanding cyst fishery on the Great Salt Lake in Utah. Because of the potential increase in harvest activities, the fishery was placed under the developmental fishery project which allowed a limit to the number of permits issued and an opportunity to collect information needed for a management plan.

A review of the basic life history and ecology of Lake Abert was conducted. Brine shrimp can be found in salt lakes and brine ponds through out the world. They thrive in extreme environmental conditions such as high salinity and temperature, where predators cannot survive. Brine shrimp are filter-feeders, ingesting organic detritus and microscopic algae and bacteria. Due to the absence of predators and competitors, *Artemia* densities are mostly controlled by food limitations.

Lake Abert is a large closed-basin, saline/alkaline lake located in south-central Oregon. At high levels, Lake Abert covers over 64 square miles, is about 16 miles long and 6 miles wide, and has a maximum depth of more than 15 feet. The size of the lake varies considerably depending on its surface elevation, which varies with climatic changes. The Chewaucan River and precipitation are the two most important sources of water for Lake Abert. The dissolved-solid content of the lake fluctuates considerably, but generally ranges from 20,000 to 80,000 ppm, and has reached as high as 115,000 ppm. Because the lake is a unique ecosystem, the Bureau of Land Management has designated the area as an Area of Critical Environmental Concern.

Previous studies conducted on birds, brine shrimp, and other invertebrates of Lake Abert were summarized. In 1981-82, the brine shrimp biomass was calculated to be approximately 7.0 $X\ 10^6$ kg with a peak in abundance in midsummer. Fragments of mats made up of algae and diatoms break loose and form floating algae spheres which were actively sought after by feeding brine shrimp. In 1983-84, 14 species of benthic macroinvertebrates were collected at Lake Abert with the alkali fly usually being the most numerous. Lake Abert is an inland staging and stopover point for fall migrants in the Pacific Flyway. Large numbers of water-dependent birds rest and feed at the lake before continuing in their southward migration. Seven species of water-dependent birds were studied at Lake Abert in 1982-83 during the fall migration to determine their diets and foraging strategies. In addition to fall migrations, 33 species of waterfowl and shorebirds passed through Lake Abert in large numbers in the spring in 1988-89.

The Great Salt Lake in Utah supplies approximately 80% of the worlds supply of brine shrimp cysts. The maximum harvest was over 14 million pounds in 1995-96. The harvest methods have become very high tech, very expensive, and very competitive.

Adult brine shrimp have been harvested in Oregon from Lake Abert 1979. Under the developmental fisheries program, a limited number of permits to harvest brine shrimp were

allowed, with separate harvest programs for the adult and cyst fisheries. Closed periods were established to protect nesting and migration seasons for bird populations. Harvest for both fisheries was also restricted to the south half of the lake to reduce disturbances to bird populations. The harvest of adults has continued as in the past. There has been no harvest of cysts due to a lack of harvestable cysts, probably due to water conditions.

A pilot sampling project was conducted to determine what levels of monitoring and sampling would be needed to develop a management plan for commercial harvest of cyst and adult brine shrimp from Lake Abert. The estimated population of adult brine shrimp in October 1997, was estimated to be 1.9×10^{11}. If all three permit holders had taken their entire quota of 50,000 pounds of adult shrimp each, the commercial harvest would have accounted for approximately 1.8% of the total available biomass of shrimp. High percentages of empty shells were found in the floating "slicks" of cysts which means the viable cysts were not on the surface of the lake and therefore not available for harvesting. The lack of floating cysts may be due to the low salinities of the Lake. Given the wet weather patterns in Oregon in the last few years and predictions for the near future, it may be some time before the lake will be at the level and salinities necessary to produce harvestable amounts of cysts.

A much more detailed, multi-year study would be needed to provide complete sustainable yield information. A major gap in information is what happens in the lake at high salinities. Recommendations for future management include to continue present adult permits and discontinue the cyst permit.

INTRODUCTION

Since the early 1980's, adult brine shrimp (*Artemia salina)* have been harvested from Lake Abert, Oregon and sold for aquarium fish food. In 1996, ODFW received numerous inquiries about harvesting brine shrimp cysts from Lake Abert; much of the interest coming from the expanding cyst fishery on the Great Salt Lake in Utah. Because of the potential increase in harvest activities, the fishery was placed under the Developmental Fishery Project which allowed a limit to the number of permits issued and an opportunity to collect information needed for a management plan. Basic life history information for brine shrimp is fairly well known; however, ecology in natural systems is less well known.

The goals of this project were to develop a management plan and monitoring program for commercial harvest of brine shrimp cysts and adults from Lake Abert, Oregon. The specific objectives of this report were to:

1. Review the basic life history of brine shrimp;
2. Review the available information on brine shrimp and ecology of Lake Abert;
3. Review commercial fisheries in other areas and management of commercial harvest in Oregon;
4. Conduct a pilot sampling project to determine what level of monitoring and sampling would be needed to develop a management plan for commercial harvest of cysts and adult brine shrimp at Lake Abert, Oregon;
5. Make recommendations for future harvest and monitoring.

LIFE HISTORY OF BRINE SHRIMP

Ecology

Brine shrimp can be found in salt lakes and brine ponds through out the world (Sorgeloos, 1980; Sorgeloos, et al., 1986). They thrive in extreme environmental conditions such as high salinity and temperature, where predators cannot survive (Sorgeloos, et al., 1986).

Temperature thresholds are different for different strains of *Artemia* (Persoone and Sorgeloos, 1980). In general, brine shrimp can survive in temperatures between 6° C and 40° C, with the optimum in the range of 25° C to 30° C. The dehydrated cysts tolerate a much wider temperature range, which never occurs in nature: absolute zero (-273° C) to almost 100° C (Persoone and Sorgeloos, 1980).

Brine shrimp have been found in supersaturated brines at salinities as high as $340^{\circ}/_{oo}$ (Persoone and Sorgeloos, 1980; Sorgeloos, 1980). The lower salinity limit in which *Artemia* is found in nature, is in most cases a function of the presence of predators (Persoone and Sorgeloos, 1980). *Artemia* can survive in seawater or brackish water, but have no defenses against predation (Sorgeloos, et al., 1986). As a general rule, lower salinity limits vary from place to place depending on the upper salinity tolerance level of local predators (Persoone and Sorgeloos, 1980).

Reproduction and growth

Brine shrimp have the ability to reproduce by two different methods depending on environmental conditions. Under favorable conditions, fertilized eggs can develop directly into free-swimming nauplii (Sorgeloos, 1980). Under extreme environmental conditions (high salinity, low oxygen levels), eggs are surrounded by a thick shell and deposited as cysts which will remain inactive as long as they are kept dry or under anaerobic conditions; they will start to develop when the salinity drops below a certain threshold. At salinities above this threshold, cysts will not hatch because they cannot hydrate enough (Sorgeloos, 1980). The salinity threshold at which cysts will hydrate is different for different strains of *Artemia* (Persoone and Sorgeloos, 1980). When the conditions are right for hatching, within a matter of hours (Sorgeloos, 1980; Sorgeloos, et al., 1986), the cysts hatch into nauplii which grow to adults in a few weeks (Persoone and Sorgeloos, 1980).

Adult animals reach 8-10 mm long (Sorgeloos, 1980). Under optimal conditions, brine shrimp can live for several months and reproduce at a rate of up to 300 nauplii or cysts every 4 days (Sorgeloos, et al., 1986). Cysts can survive for years and only have to be incubated for 24 hours in seawater to produce larvae (Sorgeloos, 1980).

Food

Brine shrimp are filter-feeders, ingesting organic detritus and microscopic algae and bacteria (Persoone and Sorgeloos, 1980; Sorgeloos, et al., 1986). In many areas, the presence of high numbers of shrimp often coincides with blooms of microscopic algae (Persoone and Sorgeloos, 1980).

Artemia can be subject to serious predation in situations where the predator can withstand the harsh environmental conditions . Numerous fish and crustacean species and some insects regularly prey on brine shrimp. One group of animals which is not so limited by the salinity barrier is birds. *Artemia* can be an important part of the diet of several species of waterfowl, gulls, avocets, and flamingos (Persoone and Sorgeloos, 1980).

Population

Due to the absence of predators and competitors, *Artemia* densities are mostly controlled by food limitations (Sorgeloos, et al., 1986).

The principal method of dispersion of *Artemia* is transportation of cysts by wind and waterfowl, as well as deliberate inoculation by humans into solar salt works (Persoone and Sorgeloos, 1980; Sorgeloos, et al., 1986).

ECOLOGY OF LAKE ABERT

Description

Lake Abert is a large closed-basin, saline/alkaline lake located in south-central Oregon, approximately 25 miles north of Lakeview. Unless otherwise cited, the following description was taken from Phillips and Van Denburgh (1971). At high levels, Lake Abert covers over 64 square miles, is about 16 miles long and 6 miles wide, and has a maximum depth of more than 15 feet. The size of the lake varies considerably depending on its surface elevation, which varies with climatic changes. Recent historic (last 100 years) high levels of about 4,262 feet above sea level were recorded in the mid 1980's (Figure 1). During several years in the early 1930's the lake was completely dry. During Pleistocene times, a larger lake occupied the deep Abert basin, where shoreline deposits were left more than 200 feet above the present-day lake bed.

Within one mile of the east edge of the lake is Abert Rim, a fault-scarp ridge which rises 1,500 to 2,200 feet above the lake. West of the lake, the surface of a tilted fault block slopes more gently to Goglan Buttes. To the north, mud flats merge into hilly terrain. At the southern end, the Chewaucan River, the lake's principal tributary, enters into the lake.

The Chewaucan River and precipitation are the two most important sources of water for Lake Abert. There are many springs that emerge along the shore on all sides of the lake, however, most of them make no material contribution to the water supply of the lake. Water loss from the lake is only through evaporation.

The dissolved-solid content of the lake fluctuates considerably, but generally ranges from 20,000 to 80,000 ppm, and has reached as high as 115,000 ppm (Keister, 1992). The three most

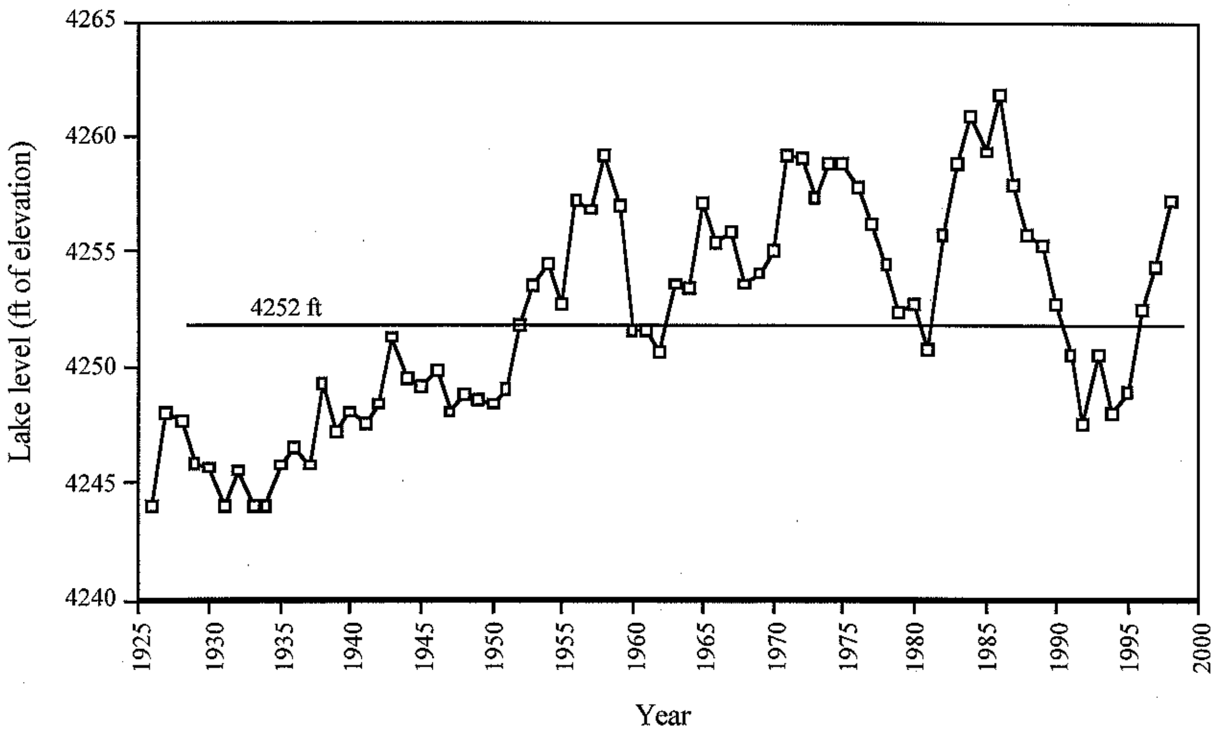

Figure 1. Water level of Lake Abert, Oregon, 1926-1998. 1926-1990 data from Keister, (1922). 1990-1996 data from Lakeview Watermaster, Oregon Water Resources Department. 1997-1998 data from personal observation. Lake levels were those taken as close as possible to October each year. Data are listed in Appendix A.

abundant dissolved constituents, sodium, carbonate, and chloride, make up about 90% of the dissolved solids. Except at near-dryness stage, the relation between dissolved-solids concentration and lake level is almost constant for Lake Abert over periods of several years. The only way the lake can lose salts is through precipitation of salts or through removal by wind in dry years (Van Denburgh, 1975).

Water temperatures in the winter range from 0°C to 5°C with some ice formation near the entrance of the Chewaucan River (Conte and Conte, 1988). In the spring, the lake warms and forms a temporary thermocline which is broken down by wave action. The lake achieves an isothermal condition with nearly constant temperature (approximately 22°C) for several weeks at a time. Gradual cooling occurs in the autumn (Conte and Conte, 1988).

Management designations

Most of the land surrounding Lake Abert is owned by the Bureau of Land Management (BLM). A permit is need by the BLM for access to the lake for commercial harvest of brine shrimp. Because the lake is a unique ecosystem, the BLM has designated the area as an Area of Critical Environmental Concern (ACEC). This designation allows the BLM to establish a management plan for the area, including standards such as water quality, to protect significant resources in the area. The BLM recognizes four important resource values or processes in the Lake Abert area that deserve special management attention: wildlife resources, cultural resources, scenic value, and ecological processes (Bureau of Land Management, 1996). The harvest of brine shrimp or cysts would not affect water quality and is therefore allowed in the ACEC.

Brine shrimp

In the early 1980's, Conte and Conte (1988) estimated the distribution, abundance, and biomass for brine shrimp in Lake Abert. The brine shrimp biomass was calculated to be approximately 7.0 X 10^6 kg with a peak in abundance in midsummer. They found no vertical stratification of shrimp between the surface and the bottom. However, horizontal distribution of shrimp was quite patchy. They estimated the annual commercial harvest in 1981 to 1983 (7,500 lb - 10,800 lb) to be approximately 0.05 % of the estimated shrimp biomass. They also estimated the maximum utilization of brine shrimp by shovelers and eared Grebes for a migratory period to be 1125 kg.

Boula (1985) found brine shrimp occurred frequently only in the diets of eared grebes (mostly adult shrimp), and shovelers (mostly cysts). Although low in frequency, adult brine shrimp were considered among the most preferred foods for ring-billed and California gulls. Low proportions of shrimp in diets of birds at Lake Abert may have reflected reduced levels of absolute availability during the time frame of the study.

Other invertebrates

Boula (1985) investigated what prey organism were available to migrating birds and documented patterns of use of prey species. Prey species included brine shrimp (*Artemia*), alkali fly (*Ephydra hians*), long-legged flies (*Hydrophprus plumberus*), amphipod (*Hyallela azteca*), waterflea (*Moina* sp.), and the beetle (*Hygrotus masculinus*). She found peak sample biomass of bird prey species in August and September. The alkali fly was the primary prey of birds at Lake Abert during autumn; alkali flies accounted for at least 65 % of the biomass consumed by each species except the northern shoveler.

Herbst (1988) collected 14 species of benthic macroinvertebrates at Lake Abert with the alkali fly usually being the most numerous. The two southernmost sites, closest to the Chewaucan River, had the greatest number of species. Species diversity declined the further north the sample site, i.e. farther from the river (the source of colonization) and more saline.

Algae

Conte and Conte (1988) found the dominant alga at Lake Abert was *Ctenocladus circinnatus*, a filamentous green alga which grew on the muddy bottom or on submerged rock near the shore. Large mats comprised of *Ctenocladus* zoospores, the diatoms *Navicula* and *Nitzschia* and the blue-green algae *Anabena* and *Oscillatoria* form on submerged mud flats. Fragments of these mats break loose and form floating algae spheres which were actively sought after by feeding brine shrimp.

Birds

Lake Abert is an inland staging and stopover point for fall migrants in the Pacific Flyway. Large numbers of water-dependent birds rest and feed at the lake before continuing in their southward migration (Boula, 1985). Morawski and Stern (1991, as cited in Keister, 1992) estimated about 1,300,000 use-days by shorebirds from July through September, 1991.

Boula (1985) studied seven species of water-dependent birds at Lake Abert during the fall migration to determine their diets and foraging strategies. Birds included in this investigation were the northern phalarope, Wilson's phalarope, American avocet, eared grebe, ring-billed gull, California gull, and northern shoveler. These species comprised the majority of all birds observed at the lake during both years of the study.

Peak numbers of Wilson's and northern phalaropes occurred in August. No Wilson's phalaropes were observed after mid-September. Northern phaloropes were observed as late as mid-October. The numbers of avocets peaked in mid-August one year and mid-July the next. Eared grebes peaked in early-August and numbers stayed relatively high throughout September and October. Some adult grebes observed early in June may have nested at the lake. Northern shovelers were the latest arrivals; with peak numbers at mid-October and early-September.

Although relative proportions varied, the alkali fly was the primary prey of birds at Lake Abert during the autumn. Alkali flies accounted for at least 65% of the biomass consumed by each species, except the northern shoveler. Brine shrimp occurred frequently only in the diets of eared grebes (35.5%, mostly adult shrimp), and shovelers (41.6%, mostly cysts). Although low in frequency, adult brine shrimp were considered among the most preferred foods for ring-billed and California gulls. Low proportions of shrimp in diets of birds at Lake Abert may have reflected reduced levels of absolute availability. Conte and Conte (1988) estimated the maximum utilization of brine shrimp by shovelers and eared Grebes for a migratory period to be 1,125 kg.

In addition to fall migrations, shorebirds pass through Lake Abert in large numbers in the spring (April & May). Kristensen, et al. (1991) observed 33 species of waterfowl and shorebirds using the lake edge habitat at the north end of the lake in 1988 and 1989, with 10 of these species as known breeders at Lake Abert (Table 1). Common spring migrants included western sandpipers, least sandpipers, dunlins, semipalmated plovers, red-necked phalaropes, and Wilson's phalaropes. Most breeders utilized the open playa or the adjacent saltgrass flats on the north lake edge. The most numerous breeder at Lake Abert was the American avocet, with an estimated 1,000 breeding birds in May. Approximately 100 pairs of western snowy plovers were observed with peak nesting between mid-May and mid-June. The breeding populations of snowy plovers at Lake Abert is the largest in Oregon (Page and Bruce, 1989 as cited in Kristensen, et al., 1991). The western snowy plover is listed as threatened in Oregon and is a federal "category 2" candidate species. There were an estimated 40 pairs of long-billed curlews nesting along the north end of the lake. Curlews are also a federal "category 2" candidate species (Kristensen, et al., 1991).

Table 1. Waterfowl and shore birds found in the lake edge habitat on the north shore of Lake Abert, with abundance greater than rare. * = known breeders at Lake Abert. (from Kristensen, et al., 1991).

Pied-billed Grebe	Canada Goose *	Black-bellied Plover	Franklin's Gull
Eared Grebe	Green-winged Teal	Snowy Plover *	Bonaparte's Gull
	Mallard *	Semipalmated Plover	Ring-billed Gull
White Pelican	Northern Pintail	Killdeer *	California Gull
	Blue-winged Teal	American Avocet *	Forster's Tern
	Cinnamon Teal *	Willet *	
	Northern Shoveler *	Marbled Godwit	
	Gadwall *	Western Sandpiper	
	American Wigeon	Least Sandpiper	
	Redhead	Dunlin	
	Lesser Scaup	Long-billed Dowitcher	
	Ruddy Duck	Wilson's Phalarope *	
		Red-necked Phalarope	

COMMERCIAL HARVESTING OF BRINE SHRIMP

Fisheries in other areas

The Great Salt Lake in Utah supplies approximately 80% of the worlds supply of brine shrimp cysts. The maximum harvest was over 14 million pounds in 1995-96 and the price has been as high as $25 per pound for cleaned cysts (Ross, 1996). The brine shrimp industry began on the Great Salt Lake in the 1950's when adult shrimp were harvested for aquarium fish food. In the 1970's the industry began harvesting cysts which are used in commercial aquaculture of shrimp, prawns, and some fish, primarily in SE Asia and South America (US Geological Survey, 1997; Ducey, 1998).

In 1996, the Utah Department of Wildlife Resources began a limited entry system for brine shrimp issuing 79 "certificates" for $10,000 each. The harvest methods have become very high tech, very expensive, and very competitive (Ducey, 1998). Spotter planes with high-tech communications are used to locate cysts; high powered vessels, oil-skimming equipment, rotary drums, and sump pumps are used to harvest the cysts (Ross, 1996; Ducey, 1998). Streaks of floating cysts are surrounded by the oil-skimming booms and then pumped into large woven bags that allow the water to drain (Allen, 1996; Ducey, 1998). The cysts are then washed, dried, packaged into one pound vacuum cans, and shipped around the world (Allen, 1996).

Oregon harvest & management

Adult brine shrimp have been harvested in Oregon from Lake Abert by one harvester since 1979. Annual landings in the last ten years have averaged over 28,000 lb (ODFW landing records). Conte and Conte (1988) estimated the annual commercial harvest in 1981 to 1983 (7,500 lb - 10,800 lb) to be approximately 0.05 percent of the estimated shrimp biomass.

Because of the expansion of the cyst fishery on the Great Salt Lake, in 1996, ODFW received numerous inquiries from harvesters looking for new harvest areas. The increased interest in harvest of cysts from Lake Abert prompted ODFW to place the fishery under the developmental fishery program in 1997.

Under the developmental fisheries program, a limited number of permits were allowed, with separate harvest programs for the adult and cyst fisheries: three permits to harvest brine shrimp adults and one permit to harvest brine shrimp cysts. Closed periods were established to protect nesting and migration seasons for bird populations. Harvest of adults was allowed from May through August and harvest of cysts was allowed, initially, from January through March. The season for cysts was expanded, beginning in 1998, to include November through December. Harvest for both fisheries was also restricted to the south half of the lake to reduce disturbances to bird populations. The adult permits were limited to a maximum annual harvest of 50,000 lb per permit and the cyst permit was limited to a maximum annual harvest of 25,000 lb. Both permits had annual renewal requirements of 5,000 lb.

Since 1997, the harvest of adults by the harvester has continued. The other adult permits have been issued but not actively used. There has been no harvest of cysts due to a lack of harvestable cysts, probably due to water conditions.

PILOT SAMPLING PROJECT

The objectives of the pilot sampling project were to determine what levels of monitoring and sampling would be needed to develop a management plan for commercial harvest of cyst and adult brine shrimp from Lake Abert.

Methods

Sample stations were chosen based on the stations used in Conte and Conte (1988) to facilitate comparisons. The shoreline of the lake was digitized from US Geological Survey (USGS) quad maps (map number's 685, 686, 245, & 246). The latitude and longitude and UTM coordinates of the stations were calculated from the digitized map and entered into a handheld GPS to locate the stations on the lake (Figure 2 and Appendix B).

At each station, three samples of brine shrimp were taken using a 30 cm diameter, 120 μm plankton net, towed from near the bottom to the surface. The net was not placed directly on the bottom, but as close to the bottom as possible without disturbing the layer of fine sediment on the bottom which would otherwise plug the plankton net.

At each station, ph, temperature, and salinity data were also collected (Appendix C) using a hand held ph meter, a hand held thermometer and a refractometer. The water level of the lake was determined from a gaging station located on the east shore of the lake (Figure 2).

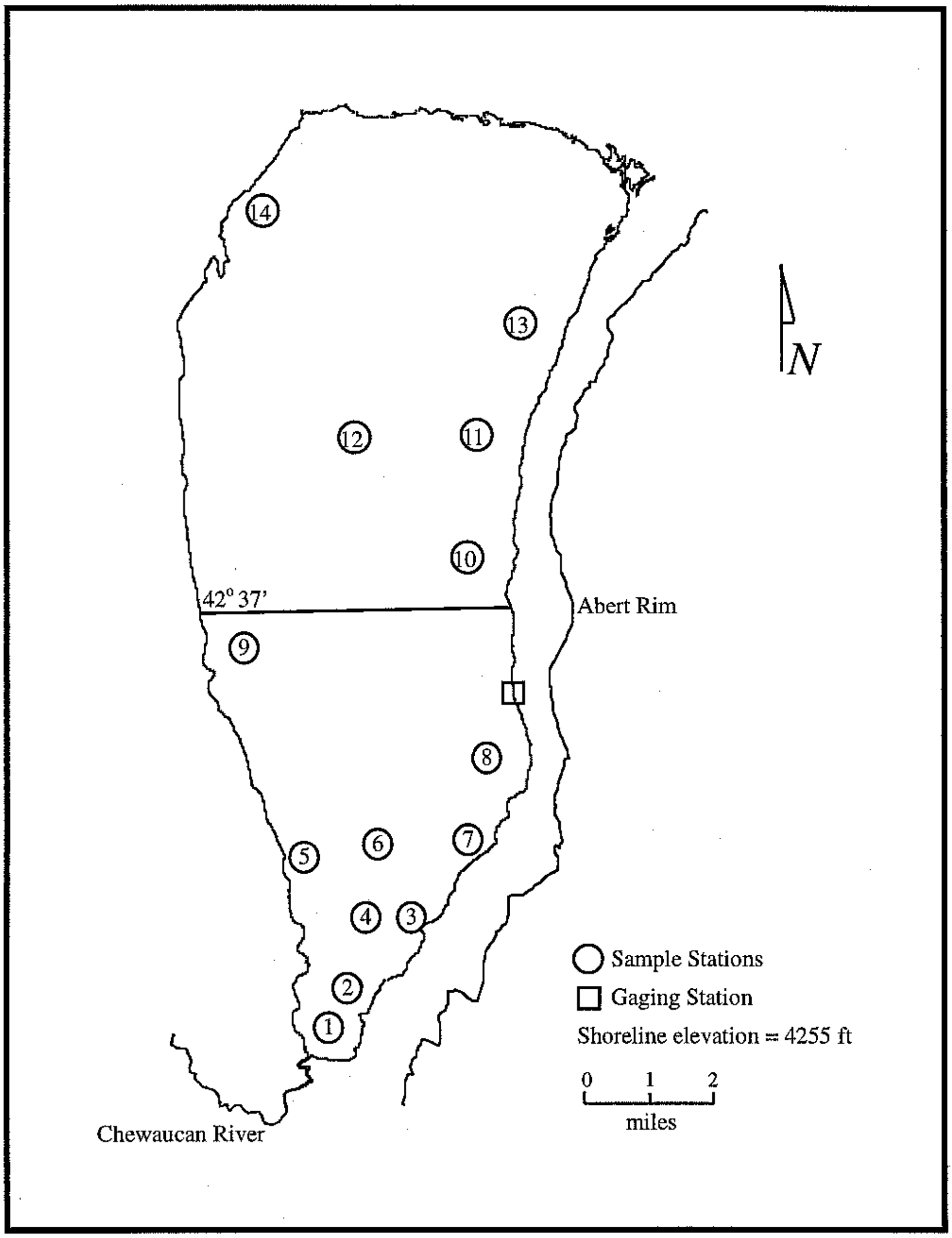

Figure 2. Map of Lake Abert showing sample stations (1-14), gaging station, and north/south dividing line.

Samples of brine shrimp were fixed in the field with 5% formalin and then transferred to 70% isopropyl alcohol a day or two later. Counts were made by either counting the entire sample (when the sample was small enough) or by subsampling from a grid sampler. Shrimp were distributed as evenly as possible over the grid sampler and subsamples were chosen by the roll of dice. Life stages were determined by microscopic examination and classified into nauplii, juveniles, and adult males and females following Heath (1924).

A number of samples of cysts were collected and analyzed for hatching rates. The samples were collected from "slicks" in the water or on the shore of the lake and sent to Avocet Artemia, Inc., in Salt Lake City, Utah for analysis.

Results and discussion

sampling conditions

We were able to sample all 14 stations on only two days. The weather and lake conditions were very unpredictable; some days the wind would not come up until late in the afternoon and on other days it would come up early in the morning and blow all day. For a more detailed, intense sampling program, personnel would need to be located much closer than Newport, 7 hours away. Because the weather was unpredictable, we focused the sampling on the south half of the lake (the commercial harvest area) and sampled the northern half when weather and time permitted. The October, 1998 samples were taken from the shore of the lake because we could not get on the lake at all.

water conditions

Table 2 summarizes the average salinity, temperature, ph, and lake level data. Individual station and sample data are listed in Appendix D. Average salinity ranged from a low of 37 $^{o}/_{oo}$ to a high of 51 $^{o}/_{oo}$. Average temperature ranged from 0.2° C in the winter to 23.1° C in the summer. Average ph ranged from 9.5 to 10.6. The temperature and ph data are incomplete due to equipment malfunctions. The lake level had been rising from a low in 1992, which was the lowest level since 1944 (Figure 1). Salinities and lake level were slightly lower than during the study by Conte and Conte (1988) where salinities were 54-80 $^{o}/_{oo}$ and lake level was above 4260 ft.

Table 2. Summary of water conditions at Lake Abert, 1997-1998.

Date	Stations sampled	Average salinity ($^{o}/_{oo}$)	Average temperature (°C)	Average ph	Lake level (feet of elevation)
2/97	4	42	3.1	10.2	4,255.2
5/97	8	37	17.2	9.9	4,256.1
7/97	14	35	23.1	9.5	4,255.8
10/97	14	51	9.5	9.8	4,254.4
11/97	4(**)	60	3.7		
12/6/97	3(**)	62	3.7		
12/20/97	3(**)	62	0.2		
1/98	3(**)	59	3.8		
3/98	8	47		10.6	4,254.8
10/98	5 (*)	37			4,257.3

(*) Samples were not taken at established stations, see text
(**) Samples were taken by Avocet Artemia, Inc, Salt Lake City, Utah and not at established stations, see text

brine shrimp

The capture efficiency of the plankton net was not calculated. Another study using a similar net calculated a capture efficiency of 70% (Conte, Jellison et al., 1988). Therefore, estimates from this sampling could be considered low. Table 3 summarizes the estimated density data for brine shrimp during 1997-1998. Individual station and replicate count data are listed in Appendices E & F. The estimated population of brine shrimp was calculated by expanding the estimated average density to the volume of the lake. The volume of the lake was calculated from the lake level using the regression from Keister (1992). Densities were highest in late winter as nauplii were hatching. Over the spring and summer, densities decreased reaching the lowest levels in the fall.

Belovsky (1996) noted a similar pattern within a year for brine shrimp in the Great Salt Lake in Utah: densities increasing rapidly in the spring and then declining over the summer. He suggests that this pattern occurs in the Great Salt Lake because the shrimp population is food-limited: within an individual year, "as the season progresses, the shrimp may reduce algal abundance by consumption and this effect is enhanced as the shrimp become larger which increases each individual's consumption.". He also noted that between years, the monthly algal abundance is statistically correlated with the average salinity of the lake for the year so that algal abundance is lowest at very low and very high salinities and the average brine shrimp density was positively correlated with the largest algal abundance in a year. "This indicates that brine shrimp populations tend to be food-limited" in The Great Salt Lake. It would be helpful to determine the salinity tolerances of the *Ctenocladus circinnatus*, algae to determine if Lake Abert brine shrimp may also be food-limited.

In a study at Lake Abert in 1981-1982, Conte and Conte (1988) made density, population, and biomass estimates of brine shrimp. "The total lake wide population of brine shrimp derived from the 14 collecting stations was estimated to be 3.4×10^{11} adults with an estimated biomass of 6.6×10^{6} kg." The salinities during Conte's study was above $80^{0}/_{00}$ during the first year and dropped to less than $40^{0}/_{00}$ in the second year after "the lake received large amounts of freshwater as a result of heavy spring inflows". The volume of the lake was calculated to be 675×10^{6} m^3 (it is not clear whether this volume was in 1981 or 1982 or at what time of year). This volume would convert to a level of above 4260 feet of elevation using the equations by Keister (1992).

From the present study's data, the estimated population of adult brine shrimp in October 1997, was 1.9×10^{11} (Table 3), a little over half that in Conte's study. Using Conte's conversion of adults per kg, the estimated biomass in October, 1997 would be 3.7×10^{6} kg or 8.2 million pounds. Only one permit holder harvested a minimal amount of shrimp in 1997, but if all three permit holders had taken their entire quota of 50,000 pounds each, the commercial harvest would have accounted for approximately 1.8% of the total available biomass of shrimp.

Variations in salinity of saline lakes can result in different species distribution, abundance, and composition (Herbst, 1988; Stevens, 1990). Herbst (1988) proposed a model suggesting abundance of species in saline lakes reaches a maximum at salinities intermediate between the physiological limitation of high salinity and the ecological limitations imposed by a diverse community at low salinity. Multiple years of data are needed, especially at higher salinities, to determine what might be "typical" population levels. Personal observations by Keith Kruise (Oregon Desert Brine Shrimp Co. Portland, OR, personal communication) suggest 1997 was below average in its population of brine shrimp.

This study did not look at vertical distribution of shrimp, but did notice a large variation in density between stations (Table 4), as did Conte and Conte (1988). They found little vertical stratification of shrimp between the surface layer and the bottom, but quite a patch horizontal spatial distribution during periods of peak abundance. We used the estimates of inter-station variance (in the formula by Prepas, 1984) in order to determine the number of sampling station that would be needed for future monitoring. The formula used is: $n = s^2/D^2X^2$; where n = number of sampling stations; s^2 = population variance; D = size of the ratio of the standard error to the mean (in this case, 25%); and X = mean density of shrimp. The estimated number of sampling stations needed to produce a standard error estimate of 25% of the mean varied from 1 to 16 (Table 4). During summer and fall, when densities are lower, the eight sampling stations on the southern half of the lake would probably be adequate to document shrimp abundance. During late winter and spring, when densities are higher, more stations may be needed.

In the late winter samples, all brine shrimp in Lake Abert were in the nauplii stage (Table 5). Over the spring and summer, the shrimp matured to juveniles and then almost all were adults in the fall. In the fall samples, a few nauplii were again present, possibly indicating the beginning of a second cohort. The counts of nauplii in the fall samples may be slightly low. Large numbers of water fleas (*Moina* sp.) in the fall samples made it difficult to distinguish the nauplii. Initially in the spring, all adult shrimp appeared to be males (Table 5). By fall, the sex ratio was close to even. In the Great Salt Lake, Gliwicz, Wurtsbaugh et al. (1995) found the population of brine shrimp consisted of two generations; one was from rapidly-growing adults that hatched from over-wintering cysts and then were gone by early June. These adults produced a second generation which grew much more slowly and only a small proportion attained maturity, "suggesting that many were unable to find sufficient food... and died of starvation". Multiple generations have been also reported in other areas: two generations have been consistently observed in Mono Lake, CA; four and eight generations have been estimated in other California areas (Lenz and Browne, 1991). "Several factors, including temperature and length of growing season, are probably important in determining the number of generations per year" (Lenz and Browne, 1991). Again, multiple years of data are needed to determine if the "normal "pattern in Lake Abert is mainly just one cohort or if different water conditions would produce multiply cohorts.

Table 3. Estimated average density (m^3) and population of brine shrimp by date, on Lake Abert, 1997-1998.

Date	Estimated average density of brine shrimp (m^3)	Lake level (feet of elevation)	Lake volume (acre feet)	Estimated population of brine shrimp (10^{12})
2/97	44,462	4,255.2	282,250	15.5
5/97	8,801	4,256.1	315,712	3.4
7/97	2,477	4,255.8	304,405	0.8
10/97	670	4,254.4	255,422	0.2
3/98	77,753	4,254.8	269,611	22.8
10/98	-	4,257.3	362,481	-

Table 4. Average density (m^3), number of sampling stations, 95% confidence interval, coefficient of variation, and number of stations that would have been required to produce standard errors of 25% of the mean on each sampling date for brine shrimp from Lake Abert, 1997-1998.

Date	Average density (m^3)	Number of sample stations	95% confidence interval	Coefficient of variation	Estimated N for 25% SE
2/97	44,462	3	24,376	0.22	1
5/97	8,801	8	7,244	0.98	16
7/97	2,477	4	1,439	0.37	2
10/97	670	14	118	0.31	2
3/98	77,753	8	41,781	0.64	7

Table 5. Average percent by life stage (nauplii, juvenile, adult) and sex ratio of adults for brine shrimp from Lake Abert, 1997-1998. P = present, but less than 1%. Individual station and replicate data are listed in Appendices G and H.

Date	Average percent by life stage			Average percent of adults by gender	
	nauplii	juvenile	adult	males	females
2/97	100	0	0	-	-
5/97	5	95	P	100	0
7/97	P	93	7	66	34
10/97	3	P	97	52	48
3/98	100	0	0	-	-

brine shrimp cysts

During most trips to the lake from fall until spring, "slicks" of cysts could be seen on the lake surface or along the shore. However, no cysts could be located anywhere on the October, 1998 trip. The samples of cysts taken were not of a quantitative nature: we did not look at factors that affect the abundance of cysts. However, there are factors that seem to have an effect on the availability of cysts for harvest purposes. The hatching rates and percent of empty shells in the samples are summarized in Table 6. Almost all the cysts collected were empty shells.

Initially, the harvest season for cysts was set at January through March. When the high percent of empty shells was noted in the first samples in January, we speculated the shrimp had already hatched. The permit holder then requested the season be adjusted to open in November to be able to harvest the cysts before they hatch; the request was approved. However, continued samples of floating cysts, even in November and December, showed the same high percent of empty shells. Stevens (1990) noted that as the salinity in the Great Salt Lake decreases, the hard winter eggs produced by the shrimp sink to the bottom of the lake. We believe the same thing happened at Lake Abert at the salinities present during 1997-1998. It is also possible, the shrimp in this lake produce cysts that sink as do the shrimp in Mono Lake, California (Persoone and Sorgeloos, 1980; Lenz and Browne, 1991).

The high percent of empty shells in the floating "slicks" of cysts means the viable cysts were not on the surface of the lake and therefore not available for harvesting. For a brine shrimp cyst harvesting and marketing endeavor to be successful, it would be necessary to have much higher yield of viable cysts: i.e., lower shell percentages (<10%) and higher hatching percentages (>70 and preferably 90%) (Brad Marden, Avocet Artemia, Inc. ., Salt Lake City, Utah, personal communication). Further investigations would be needed to determine if the shrimp from Lake Abert will produce floating cysts and the optimum salinity for an adequate supply of floating viable cysts for a commercial harvest operation.

Brad Marden (Avocet Artemia, Inc., Salt Lake City, Utah, personal communication) believes the salinity would need to be above the 80-100 ppt range for a large enough quantity of viable cysts to be available for commercial harvest. Since the salinity of the water is related to the lake level, the level of the lake would have to be below approximately 4252 feet of elevation to achieve salinities in the 80-100 ppt range (Keister, 1992); below the average level of the last 50 years. The level of the lake was below 4252 feet several years in the early 1990's (Figure 1), but in only four other years since 1953. The winter of 1998-99 continues a wet weather pattern: total precipitation for the water year (starting October 1, 1998) is 124% of average and streamflow forecast for the Chewaucan River for March through July, 1999 is 165% of average (NWCC, 1999). Taylor (1999) believes weather patterns indicate Oregon is entering a wet weather period which may last 20 years. Given the rise in water level in the last few years (Figure 1), it seems unlikely the level will drop below 4252 feet in the next few years.

Table 6. Percent of hatched cysts and empty shells in samples of cysts from Lake Abert, 1997-1998. Samples were analyzed by Avocet Artemia Inc., Salt Lake City, Utah.

Date	Cysts hatch %	Shell %
2/97	0.0	100.0
11/97	1.9	90.9
12/6/97	4.0	94.9
12/20/97	2.7	94.7
1/98	4.1	86.6
2/98	0.0	100.0
3/98	0.0	100.0
10/98	no cysts located	

RECOMMENDATIONS

Future studies

A much more detailed, multi-year study would be needed to provide complete sustainable yield information:

- If a more intense sampling program is undertaken in the future, personnel need to be located much closer than Newport.
- During summer and fall, when densities are lower, the eight sampling stations on the southern half of the lake would probably be adequate to document shrimp abundance.
- During late winter and spring, when densities are higher, more stations may be needed.
- Updated conversions of adults per kg are needed to estimate biomass.
- Both this study and the study by Conte and Conte (1988) occurred when the salinities were relatively low. A major gap in information is what happens in the lake at high salinities:
  - Are brine shrimp more abundant at higher salinities? What is the upper tolerance limits? At what salinities is the population at its highest level?
  - Is more than one cohort a season produced at higher salinities?
  - Are brine shrimp at Lake Abert food-limited? What are the salinity tolerances of the *Ctenocladus circinnatus*, algae?
- The present level and timing of harvest activity, basically only one permit during the summer, does not seem to cause any significant disturbance to bird populations. If there is an increase in activity, especially at other times of the year, additional information would be needed on the effects of harvest activity on bird populations.

Future management

adults

The main increase in interest in brine shrimp has been for cysts rather than adults; the additional permits for adult harvest have been issued but none were used. As long as the present level of interest for adults continues, the current level of permits appears to be sufficient to allow some turnover in permits but not an over harvest of shrimp.

cysts

If the salinity needs to be above the 80-100 ppt range to provide enough floating cysts for a commercial harvest operation, the level of the lake would need to drop to approximately the 4252 ft level to achieve these conditions; below the average level of the last 50 years. The level of the lake was below 4252 feet several years in the early 1990's, but in only four other years since 1953. Given the wet weather cycle and rise in water level in the last few years, it seems unlikely the level will drop below 4252 feet in the next few years. Therefore, we recommend the permit for cyst harvesting be discontinued.

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REFERENCES

Allen, B. 1996. The brine shrimp capital of the world. Tropical Fish Hobbyist. May, 1996. pp. 86-93

Belovsky, G. E. 1996. Brine shrimp population dynamics and sustainable harvesting in the Great Salt Lake, Utah. Department of Fisheries and Wildlife/Ecology Center, Utah State University. 1996 Progress Report to the Utah Division of Wildlife Resources. Logan, Utah. 31 pp.

Boula, K. M. 1985. Foraging ecology of migrant waterbirds, Lake Abert, Oregon. MS Thesis. Oregon State University, Corvallis, OR. 99 pp.

Bureau of Land Management. 1996. High desert management framework proposed plan amendment and final environmental impact statement for the Lake Abert Area of Critical Environmental Concern (ACEC) in Lake County, Oregon. Lakeview District. Lakeview, Oregon. 42 pp.

Conte, F. P. and P. A. Conte. 1988. Abundance and spatial distribution of *Artemia salina* in Lake Abert, Oregon. Hydrobiologia 158:167-172.

Conte, F. P., R. S. Jellison and G. L. Starrett. 1988. Nearshore and pelagic abundances of *Artemia monica* in Mono Lake, California. Hydrobiologia 158:173-181.

Ducey, K. 1998. The secret of Great Salt Lake. Utah's only commercial fishery, brine shrimp, is breeding serious competition. National Fisherman. January, 1998. pp. 22-25.

Gliwicz, Z. M., W. A. Wurtsbaugh and A. Ward. 1995. Brine shrimp ecology in the Great Salt Lake, Utah. Dept. of Fisheries and Wildlife/Ecology Center, Utah State University. June 1994 - May 1995 Performance Report to the Utah Division of Wildlife Resources, Salt Lake City, Utah. Logan, Utah. 83 pp.

Heath, H. 1924. The external development of certain phyllopods. Journal of Morphology 38(4):453-483.

Herbst, D. B. 1988. Comparative population ecology of *Ephydra hians* Say (Diptera: Ephydridae) at Mono Lake (California) and Abert Lake (Oregon). Hydrobiologia 158:145-166.

Keister, G. P. 1992. The ecology of Lake Abert: Analysis of further development. Oregon Dept. of Fish and Wildlife. Technical Report. 92-5-02. 34 pp.

Kristensen, K., M. Stern and J. Morawski. 1991. Birds of north Lake Abert, Lake Co., Oregon. Oregon Birds 17(3):67-77.

Lenz, P.H. and R.A. Browne. 1991. Ecology of *Artemia*. pp. 237-253 *in*: R.A. Browne, P. Sorgeloos, and C.N.A. Trotman. *Artemia* biology. CRC Press, Boca Raton.

Morawski, J. and M. Stern. 1991. Lake Abert water bird counts. Unpublished Report. The Nature Conservancy. 9 pp.

National Water and Climate Center. 1999. Watersupply outlook report, Lake County and Goose Lake basins. (On-line). Available: ftp://crystal.or.nrcs.usda.gov/pub/wsor/or/mar/or3s30.htm.

Page, G. and C. Bruce. 1989. Results of the 1988 summer survey of snowy plovers in the interior of the western United States. Point Reyes Bird Observatory, Oregon Dept. Fish and Wildlife. Unpublished Report. 8 pp.

Persoone, G. and P. Sorgeloos. 1980. General aspects of the ecology and biogeography of *Artemia*. pp. 3-24 *in:* G. Persoone, P. Sorgeloos, O. Roels and E. Jaspers. The brine shrimp *Artemia.* Vol 3. Proceedings of the international symposium on the brine shrimp *Artemia salina.* Universal Press, Wettere, Belgium.

Phillips, K. N. and A. S. Van Denburgh. 1971. Hydrology and Geochemistry of Abert, Summer, and Goose Lakes, and other closed-basin lakes in south-central Oregon. US Dept. Interior. Closed Basin Investigations. Geological Survey Professional Paper 502-B. 86 pp.

Prepas, E. E. 1984. Some statistical methods for the design of experiments and analysis of samples. pp. 266-335 *in:* J. A. Downing and F. H. Rigler. A manual on methods for the assessment of secondary productivity in fresh waters. Blackwell Scientific Publications, Oxford.

Ross, D. 1996. Utah Department of Natural Resources. Letter dated May 16, 1996.

Sorgeloos, P. 1980. Life history of the brine shrimp *Artemia*. pp. xxix-xxiii *in:* G. Persoone, P. Sorgeloos, O. Roels and E. Jaspers. The brine shrimp *Artemia.* Vol 3. Proceedings of the International symposium on the brine shrimp *Artemia salina*. Universal Press, Wettere, Belgium.

Sorgeloos, P., P. Lavens, P. Leger, W. Tackaert and D. Versichele. 1986. Manual for the culture and use of brine shrimp Artemia in aquaculture. State University of Ghent, Belgium.

Stevens, D. W. 1990. Changes in lake levels, salinity and the biological community of Great Salt Lake (Utah, USA), 1847-1987. Hydrobiologia 197:139-146.

Taylor, G.H. 1999. Long-term wet-dry cycles in Oregon. Oregon Climate Service, Oregon State University. (On-line). Available: http//www.ocs.orst.edu/reports/wet-dry.html.

U.S. Geological Survey. 1997. Brine shrimp and the ecology of Great Salt Lake. (On-line) Available: http://wwwdutslc.wr.usgs.gov/greatsaltlake/shrimp.html.

Van Denburgh, A. S. 1975. Solute balance at Abert and Summer Lakes, south-central Oregon. US Dept. Interior. Closed Basin Investigation. Geological Survey Professional Paper 502-C. 29 pp.

APPENDICES

Appendix A. Water level data for Lake Abert, Oregon, 1926-1998. The 1926-1990 data are from Keister, (1992). The 1990-1996 data are from Lakeview Watermaster, Oregon Water Resources Department. The 1997-1998 data are from personal observation. Lake levels were those taken as close as possible to October each year.

Year	Lake level (feet of elevation)	Year	Lake level (feet of elevation)	Year	Lake level (feet of elevation)
1926	4,244.0	1951	4,249.1	1976	4,257.8
1927	4,248.0	1952	4,251.9	1977	4,256.2
1928	4,247.7	1953	4,253.5	1978	4,254.5
1929	4,245.9	1954	4,254.5	1979	4,252.4
1930	4,245.7	1955	4,252.8	1980	4,252.7
1931	4,244.0	1956	4,257.3	1981	4,250.8
1932	4,245.6	1957	4,256.8	1982	4,255.7
1933	4,244.0	1958	4,259.1	1983	4,258.8
1934	4,244.0	1959	4,257.0	1984	4,260.9
1935	4,245.8	1960	4,251.7	1985	4,259.3
1936	4,246.6	1961	4,251.7	1986	4,261.7
1937	4,245.8	1962	4,250.6	1987	4,257.9
1938	4,249.3	1963	4,253.6	1988	4,255.7
1939	4,247.2	1964	4,253.4	1989	4,255.2
1940	4,248.1	1965	4,257.2	1990	4,252.7
1941	4,247.6	1966	4,255.4	1991	4,250.6
1942	4,248.4	1967	4,255.8	1992	4,247.6
1943	4,251.3	1968	4,253.6	1993	4,250.6
1944	4,249.6	1969	4,254.1	1994	4,248.0
1945	4,249.2	1970	4,255.1	1995	4,249.0
1946	4,249.9	1971	4,259.1	1996	4,252.5
1947	4,248.1	1972	4,259.1	1997	4,254.4
1948	4,248.9	1973	4,257.3	1998	4,257.3
1949	4,248.7	1974	4,258.8		
1950	4,248.4	1975	4,258.8		

Appendix B. UTM, latitude/longitude coordinates of sample stations, and north/south division line.

Station	UTM (mN)	UTM (mE)	Latitude	Longitude
1	4711717	726580	42° 31' 35.2"	120° 14' 28.9"
2	4712866	726633	42° 32' 05.9"	120° 14' 25.2"
3	4714471	728544	42° 32' 55.8"	120° 12' 29.2"
4	4714339	727372	42° 32' 52.8"	120° 13' 50.7"
5	4715936	725751	42° 33' 46.2"	120° 14' 59.4"
6	4716154	727612	42° 33' 51.3"	120° 13' 37.6"
7	4716148	729661	42° 33' 48.9"	120° 12' 07.8"
8	4718301	730315	42° 34' 57.9"	120° 11' 36.1"
9	4720706	724462	42° 36' 22.0"	120° 15' 49.1"
10	4722750	729779	42° 37' 22.6"	120° 11' 56.0"
11	4725613	730256	42° 38' 54.8"	120° 11' 28.0"
12	4725662	727202	42° 38' 59.6"	120° 13' 41.9"
13	4728537	731132	42° 40' 28.5"	120° 10' 45.3"
14	4721212	724810	42° 42' 01.9"	120° 15' 18.9"
north/south line	4722051		42° 37' 00.0"	

Appendix C. Summary of data and samples of brine shrimp and cysts collected from Lake Abert, 1997-1998. AA = Avocet Artemia Inc., Salt Lake City, Utah.

Date	Number of stations sampled	Data/samples collected						Samples collected by
		temp	salinity	ph	water level	shrimp	cysts	
2/97	4	x	x	x	x	x		ODFW
2/97							x	AA
5/97	8	x	x	x	x	x		ODFW
7/97	14	x	x	x	x	x		ODFW
10/97	14	x	x	x	x	x		ODFW
11/97	4(*)	x	x				x	AA
12/6/97	3(*)	x	x				x	AA
12/20/97	3(*)	x	x				x	AA
1/98	3(*)	x	x				x	AA
2/98	2(*)	x					x	AA
3/98	8(*)		x		x	x	x	ODFW
10/98	3(*)		x		x		(**)	ODFW

(*) Samples were not taken at established stations, see text

(**) looked for cysts but none were located

Appendix D. Bottom depth, salinity, temperature, and ph, by station, of Lake Abert during 1997 and 1998. * = equipment malfunctioned.

Date	2/28/97				5/22/97				7/11/97				10/15/97				3/12/98			
Station	Bottom depth (ft)	Salinity (ppt)	Temp (°C)	ph	Bottom depth (ft)	Salinity (ppt)	Temp (°C)	ph	Bottom depth (ft)	Salinity (ppt)	Tem p (°C)	ph	Bottom depth (ft)	Salinity (ppt)	Temp (°C)	ph	Bottom depth (ft)	Salinity (ppt)	Temp (°C)	ph
1	6.5				6.4	36	17.7	10.0	6.1	38	23.2	9.7	4.1	52	*	9.9	4.8	44	*	*
2	8.5				8.9	38	17.2	10.0	8.7	35	22.5	9.6	7.2	52	*	9.9	7.7	43	*	*
3	9.5				10.0	34	15.8	10.0	7.4	35	21.5	9.6	6.3	50	*	10.1	8.6	47	*	*
4	11.5	42	3.1	10.2	11.2	38	17.5	9.9	11.2	32	22.5	9.5	10.0	50	*	11.2	10.4	47	*	*
5					8.5	39	17.1	9.9	8.3	35	22.5	9.4	7.0	51	9.3	9.9	7.0	48	*	*
6					11.9	39	17.4	9.9	11.8	35	22.8	9.4	10.8	51	9.2	9.7	10.7	48	*	*
7					10.6	36	17.4	9.9	10.5	33	22.6	9.4	9.1	51	9.4	9.5	9.3	47	*	*
8					10.5	38	17.7	9.9	10.5	34	22.9	9.5	9.1	50	9.8	9.4	9.1	48	*	*
9									8.7	37	24.1	9.6	7.2	50	9.7	9.4				
10									10.0	35	23.9	9.4	8.8	50	*	9.1				
11									9.0	34	24.0	9.5	7.9	50	*	9.6				
12									10.8	37	24.1	9.6	7.7	51	*	9.7				
13									7.7	35	23.2	9.6	6.4	51	*	9.4				
14									5.4	37	23.5	9.6	4.0	51	*	10.2				

Appendix E. Sample depth, count, volume, and estimated density (m^3) of brine shrimp from Lake Abert during 1997 and 1998.

Date		2/28/97				5/22/97				7/11/97			
Station	Replicate	Sample depth (ft)	Sample count	Sample volume (m^3)	Est. density (m^3)	Sample depth (ft)	Sample count	Sample volume (m^3)	Est. density (m^3)	Sample depth (ft)	Sample count	Sample volume (m^3)	Est. density (m^3)
1	1	6.5				5.0	2,905	0.108	26,967	5.0			
	2					5.0	1,154	0.108	10,712	5.0			
	3					5.0	1,592	0.108	14,778	5.0			
2	1	8.5	9,877	0.183	53,933	6.0	399	0.129	3,087	8.0	133	0.172	772
	2					6.0	887	0.129	6,862	8.0	190	0.172	1,102
	3					6.0	433	0.129	3,350	8.0	578	0.172	3,353
3	1	9.5	7,029	0.205	34,342	8.0	5,025	0.172	29,154	7.0			
	2					8.0	4,468	0.172	25,922	6.0			
	3					8.0	4,317	0.172	25,046	6.0			
4	1	11.5	11,177	0.248	45,111	9.0	1,038	0.194	5,353	10.0			
	2					9.0	522	0.194	2,692	10.0			
	3					9.0	395	0.194	2,037	10.0			
5	1					6.5	1,135	0.140	8,105	7.0			
	2					6.5	951	0.140	6,791	7.0			
	3					6.5	496	0.140	3,542	7.0			
6	1					10.0	455	0.215	2,112	11.0			
	2					10.0	226	0.215	1,049	11.0			
	3					10.0	584	0.215	2,711	11.0			
7	1					9.0	964	0.194	4,971	9.0			
	2					9.0	1,020	0.194	5,260	9.0			
	3					9.0	1,217	0.194	6,276	9.0			
8	1					9.0	611	0.194	3,151	9.0	338	0.194	1,743
	2					9.0	1,042	0.194	5,374	9.0			
	3					9.0	1,148	0.194	5,920	9.0			
9	1									7.0			
	2									7.0			
	3									7.0			
10	1									9.0			
	2									9.0			
	3									9.0			
11	1									8.0	620	0.172	3,597
	2									8.0			
	3									8.0			
12	1									9.0			
	2									9.0			
	3									9.0			
13	1									6.0	365	0.129	2,824
	2									6.0			
	3									6.0			
14	1									4.0			
	2									4.0			
	3									4.0			

Appendix E (con't). Sample depth, count, volume, and estimated density (m^3) of brine shrimp from Lake Abert during 1997 and 1998.

Date		10/15/97				3/12/98			
Station	Replicate	Sample depth (ft)	Sample count	Sample volume (m^3)	Est. density (m^3)	Sample depth (ft)	Sample count	Sample volume (m^3)	Est. density (m^3)
1	1	3.5	21	0.075	278	3.5	10,490	0.075	139,110
	2	3.5	30	0.075	398	3.5	8,446	0.075	112,004
	3	3.5	42	0.075	557	3.5	8,525	0.075	113,052
2	1	6.0	114	0.129	882	7.0	5,242	0.151	34,758
	2	6.0	108	0.129	835	7.0	4,586	0.151	30,408
	3	6.0	41	0.129	317	7.0	4,860	0.151	32,225
3	1	5.0	35	0.108	325	8.0	9,914	0.172	57,519
	2	5.0	55	0.108	511	8.0	11,009	0.172	63,872
	3	5.0	58	0.108	538	8.0	12,722	0.172	73,810
4	1	9.5	162	0.205	791	10.0	14,810	0.215	68,740
	2	9.5	128	0.205	625	10.0	18,756	0.215	87,055
	3	9.5	124	0.205	606	10.0	15,970	0.215	74,124
5	1	7.0	146	0.151	968	6.0	4,219	0.129	32,637
	2	7.0	64	0.151	424	6.0	3,550	0.129	27,462
	3	7.0	70	0.151	464	6.0	6,365	0.129	49,238
6	1	7.0	45	0.151	298	10.0	38,815	0.215	180,157
	2	9.5	86	0.205	420	10.0		0.215	
	3	10.0	91	0.215	422	10.0		0.215	
7	1	8.0	121	0.172	702	9.0	10,757	0.194	55,475
	2	8.0	64	0.172	371	9.0	10,210	0.194	52,654
	3	8.0	236	0.172	1,369	9.0	6,372	0.194	32,861
8	1	8.0	156	0.172	905	8.0	10,426	0.172	60,489
	2	8.0	190	0.172	1,102	8.0	11,894	0.172	69,006
	3	8.0	114	0.172	661	8.0	10,188	0.172	59,109
9	1	6.0	103	0.129	797				
	2	6.0	87	0.129	673				
	3	6.0	101	0.129	781				
10	1	7.5	90	0.162	557				
	2	7.5	96	0.162	594				
	3	7.5	91	0.162	563				
11	1	6.5	53	0.140	378				
	2	6.5	119	0.140	850				
	3	6.5	128	0.140	914				
12	1	6.0	109	0.129	843				
	2	6.0	102	0.129	789				
	3	6.0	197	0.129	1,524				
13	1	6.0	150	0.129	1,160				
	2	6.0	114	0.129	882				
	3	6.0	93	0.129	719				
14	1	3.0	29	0.065	449				
	2	3.0	34	0.065	526				
	3	3.0	23	0.065	356				

Appendix F. Estimated density of brine shrimp (m^3) of Lake Abert during 1997 and 1998. * = samples taken, but inadequately processed.

Date	Replictate	Station 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
2/28/97	1		53,933	34,342	45,111											44,462
5/22/97	1	26,967	3,087	29,154	5,353	8,105	2,112	4,971	3,151							
	2	10,712	6,862	25,922	2,692	6,791	1,049	5,260	5,374							
	3	14,778	3,350	25,046	2,037	3,542	2,711	6,276	5,920							
	mean	17,486	4,433	26,708	3,361	6,146	1,957	5,503	4,815							8,801
7/11/97	1	*	772	*	*	*	*	*	1,743	*	*	3,597	*	2,824		
	2	*	1,102	*	*	*	*	*	*	*	*	*	*	*	*	
	3	*	3,353	*	*	*	*	*	*	*	*	*	*	*	*	
	mean		1,742						1,743			3,597		2,824		2,477
10/15/97	1	278	882	325	791	968	298	702	905	797	557	378	843	1,160	449	
	2	398	835	511	625	424	420	371	1,102	673	594	850	789	882	526	
	3	557	317	538	606	464	422	1,369	661	781	563	914	1,524	719	356	
	mean	411	678	458	674	619	380	814	890	750	571	714	1,052	920	444	670
3/12/98	1	139,111	34,758	57,519	68,740	32,637	180,157	55,475	60,489							
	2	112,005	30,408	63,872	87,055	27,462		52,654	69,006							
	3	113,052	32,225	73,810	74,124	49,238		32,861	59,109							
	mean	121,389	32,464	65,067	76,639	36,446	180,157	46,997	62,868							77,753

Appendix G. Percent of brine shrimp by life stage (n=nauplii, j=juvenile, a=adult) of Lake Abert during 1997 and 1998. P = present, but less than 1%. * = samples taken, but inadequately processed.

Date	Sub-sample	Station																							
		1			2			3			4			5			6			7			8		
		n	j	a	n	j	a	n	j	a	n	j	a	n	j	a	n	j	a	n	j	a	n	j	a
2/28/97	1				100	0	0	100	0	0	100	0	0												
5/22/97	1	0	100	P	1	99	0	0	100	0	P	99	P	P	100	0	13	87	0	11	89	0	13	87	P
	2	0	100	P	P	100	0	0	100	0	9	91	0	P	100	0	13	87	0	10	90	0	11	89	0
	3	0	100	0	0	100	0	0	100	0	9	91	0	1	99	0	11	89	P	4	96	P	10	90	0
	mean	0	100	P	P	100	0	0	100	0	6	94	0	P	100	0	12	88	0	8	92	0	11	89	P
7/11/97	1		*		0	94	6		*			*			*			*			*		0	100	0
	2		*		0	94	6		*			*			*			*			*			*	
	3		*		P	91	9		*			*			*			*			*			*	
	mean				P	93	7																		
10/15/97	1	0	5	95	2	1	97	20	0	80	1	0	99	1	1	98	0	2	98	0	1	99	3	0	97
	2	0	3	97	2	1	97	4	0	96	2	0	98	6	0	94	0	0	100	2	0	98	1	0	99
	3	0	0	100	5	2	93	17	2	81	1	0	99	4	0	96	1	0	99	1	0	99	4	0	96
	mean	0	3	97	3	1	96	14	P	86	1	0	99	4	P	96	P	1	99	1	P	99	3	0	97
3/12/98	1	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0
	2	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0				100	0	0	100	0	0
	3	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0				100	0	0	100	0	0
	mean	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0

Date	Sub-sample	Station																		Average		
		9			10			11			12			13			14					
		n	j	a	n	j	a	n	j	a	n	j	a	n	j	a	n	j	a	n	j	a
2/28/97	1																			100	0	0
5/22/97	1																					
	2																					
	3																					
	mean																			5	95	P
7/11/97	1		*			*		0	92	8		*		0	89	11		*				
	2		*			*						*						*				
	3		*			*						*						*				
	mean																			P	93	7
10/15/97	1	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	7	0	93			
	2	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	4	0	96			
	3	0	0	100	1	0	99	0	0	100	0	0	100	3	0	97	6	0	94			
	mean	0	0	100	P	0	100	0	0	100	0	0	100	1	0	99	6	0	94	3	P	97
3/12/98	1																					
	2																					
	3																					
	mean																			100	0	0

Appendix H. Percent of adult brine shrimp by gender (m=male, f=female, n=number) from Lake Abert during 1997 and 1998. * = samples taken, but inadequately processed.

Date	Sub-sample	Station 1			2			3			4			5			6			7			8		
		m	f	n	m	f	n	m	f	n	m	f	n	m	f	n	m	f	n	m	f	n	m	f	n
5/22/97	1	100	0	1							100	0	1										100		1
	2	100	0	1																					
	3																100		1	100		2			
	mean	100	0								100	0					100	0		100	0		100	0	
7/11/97	1		*		88	12	8		*			*			*			*			*			*	
	2		*		58	42	12		*			*			*			*			*			*	
	3		*		67	33	52		*			*			*			*			*			*	
	mean				71	29																			
10/15/97	1	35	65	20	58	42	111	50	50	28	52	48	161	62	38	143	57	43	44	48	52	120	56	44	152
	2	41	59	29	62	38	105	62	38	53	55	45	126	52	48	60	55	45	86	46	54	63	53	47	188
	3	45	55	42	61	39	38	52	48	47	55	45	123	43	57	67	49	51	90	49	51	234	63	37	109
	mean	40	60		60	40		55	45		54	46		52	48		54	46		48	52		57	43	

Date	Sub-sample	Station 9			10			11			12			13			14			Average	
		m	f	n	m	f	n	m	f	n	m	f	n	m	f	n	m	f	n	m	f
5/22/97	1																				
	2																				
	3																				
	mean																			100	0
7/11/97	1		*			*		64	36	47		*		62	38	39		*			
	2		*			*						*						*			
	3		*			*						*						*			
	mean							64	36					62	38					66	34
10/15/97	1	52	48	103	53	47	90	43	57	53	54	46	109	48	52	150	44	56	27		
	2	57	43	87	50	50	96	52	48	119	50	50	102	50	50	114	50	50	32		
	3	56	44	101	54	46	91	51	49	128	49	51	197	50	50	90	45	55	22		
	mean	55	45		52	48		49	51		51	49		49	51		46	54		52	48